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DECOMPOSITION OF ROCKS IN BRAZIL.

UNDER the above title Dr. J. C. Branner[1] has recently brought together an extensive series of observations scattered through the literature relating to Brazil, with many original notes of his own bearing on the subject of rock decay in that country and the causes of the exceptional character and depth attributed to it by most writers. While appreciating fully the value and interest of the facts collected in the said paper, the present writer is somewhat inclined to question the hypothesis that furnished the motive for the collection, that is to say, the hypothesis that rock decay in Brazil is of an exceptional character requiring for its explanation the operation of special causes. The subject is one in regard to which he has felt great diffidence in formulating an opinion, even for his own private use, from his lack of familiarity with other regions of like petrographical and geological structure but situated under different climatic conditions, with which alone the comparison can properly be made. As it is probable, however, that in this respect he is in the same boat with many of the writers whose observations are relied upon for establishing the major premise in the case, he ventures to present some of his own observations on certain aspects of the subject.

Professor Pumpelly treating of the secular decay of rocks[2] has well remarked that "The depths of this decay, other things being equal, is determined by lapse of time, by the permeability and by the solubility of the constituents rather than by its hardness." If under permeability we include such features of geological structure as fissibility, jointing, etc., which facilitate the access of water to the interior of rock masses independent of the structure of the rocks *per se*, and the position of the planes of such geological structure with reference to the source of water supply, the law as above stated may be taken as covering the entire question to be considered.

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[1] Bull. Geol. Soc. of Am., Vol. VII, p. 256.

[2] Bull. Geol. Soc. of Am., Vol. II, p. 210.

Of the authors who have treated of rock decay in Brazil, the two whose opinions are entitled to the most weight, Agassiz and Hartt, believed (at least at the time of writing) in the general glaciation of the country by which the element of time in the formation of the present coating of decomposition products would be materially reduced. If, as Branner has recently shown to be probable,[1] these authors afterward modified their views regarding glaciation, they would doubtless have expressed themselves very differently on the subject of rock decay. At all events, for those who, like Branner and the writer, do not believe in the glaciation of Brazil, the time element is practically unlimited and the question becomes one as to whether or not the other factors of permeability and solubility are sufficient to account for the phenomena observed.

That the decomposition of Brazilian rocks, particularly those of the crystalline and semicrystalline groups, is both widespread and profound is abundantly proven by the numerous examples cited in Branner's paper. It is even probable that the cases cited fall far short of the extremes that may be found when the country is more fully explored. Thus far, however, no authentic Brazilian example in gneiss equals that of the bed in the Hoosic Tunnel decayed to a depth of 230 feet below the outcrop (in a glaciated region be it noted) cited by Hunt,[2] or in granite that of the Cornish example rotten to the depth of 600 feet, cited by Geikie.[3] According to the latter authority, the kaolinization of the Cornish granites frequently extends to a depth of 50 or 60 feet, which represents fairly well the generality of cases of decay of this type of rock in Brazil.

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[1] JOUR. OF GEOL., Vol. I, p. 753.

[2] Am. Jour. Sci., 3d ser., Vol. XXVI, p. 198.

[3] Text-Book of Geol., 2d ed., p. 322.

Although not clearly expressed, it is evident that most writers in treating of the region about Rio de Janeiro, to which most of the observations on rock decay in Brazil refer, have assumed that the massive types of granitoid gneiss and, to a subordinate extent, of true granite, which are about the only rocks seen in a sound condition, represent the generality of rock in the region, and that the great masses of decomposed rock seen belong necessarily to these resistant types. It seems also to have been assumed that the accidents of relief giving abrupt differences of level of hundreds, or even thousands, of feet are mainly due to extraordinary erosion preceded by decay to extraordinary depths. The clearest expression of this view is found in the long-shot explanation by Agassiz of the so-called organpipe peaks (see Fig. 4 of Branner's paper) as hard vertical strata of gneiss left standing by the gradual decay of softer intervening strata. Up to the present time the peaks in question have never been examined close at hand by a competent geologist and as both gneiss and granite occur prominently in the range it is doubtful which of these two types of rock forms the peaks, or what may occur in the intervals between them.

It is certain, however, that the apparent uniformity of the massive types of rocks is due to their great resistance to decay in virtue of which they form the greater part of the hills which generally present bare rocky bosses at the summit while the flanks are heavily wooded. In the flanks between these hills basic eruptives, principally diabases, frequently appear which, though equally massive, seem to be more susceptible to decay although their apparent limitation to the lower levels may in part be due to their emergence along lines of fracture and of consequent weakness and of susceptibility to decay. Much more frequent in the lower grounds and in the hills of deeply decomposed material are schistose gneisses which from their lack of homogeneity and their position with the planes of fissibility standing nearly vertically are highly permeable and so subject to decay that they are rarely found in a sound condition and have generally been overlooked. In the absence of a detailed geological study it is impossible to estimate, even approximately, the relative areas occupied by the comparatively impermeable granitoid gneisses and granites and these highly permeable schistose gneisses, but presumably the areas formerly occupied by the latter were at least equal to those of the former.

As regards the origin of the present abrupt topographical features the importance of faulting in their formation has scarcely been hinted at, and yet, as an examination of the excellent figures accompanying the paper cited will show, it seems to afford the most natural explanation of many of these features. Admitting that faulting on an extensive scale has taken place in the region, it will be readily seen that the downthrow side of a fault will be in very different conditions as regards the agencies of decomposition (even when the same type of rock is concerned) from the upthrow side. The latter receives only the water that actually falls upon it from the clouds and the time for infiltration (until a covering of decomposed material is formed that serves to retain a portion of the water) is practically limited by the duration of the rain. Under these circumstances the granitoid gneisses and granites of Rio de Janeiro and of the Serra do Mar region generally, are so nearly impermeable that the tops of the bosses are almost always bare and waste mainly by the process of exfoliation. On the slopes where the rock may be more shattered and where talus accumulates the meteoric waters have a greater scope for action particularly after vegetation has established itself on the decomposition crust that is gradually formed which, serving as a saturated sponge, greatly prolongs the time of infiltration of the surface waters to the underlying rocks. The downthrust side of a fault in addition to its own proper share of meteoric waters receives also a large part of the drainage of the upthrust portion not only during the downpour of rain but for some time after and the access of the water to the interior of the rock mass will be facilitated by the fault plane and by any secondary shattering that may attend it. It may thus happen that in the distance of a few feet the same rock may be found almost perfectly sound and profoundly decomposed, and in cases of apparently abnormal decomposition the local conditions should be carefully studied before special causes (which will often be found to have respected adjacent rock masses) are called into play.[1]

Of the greater part of the examples that have been cited as showing the extraordinary extent of rock decay in Brazil no details regarding petrographic character and topographical position have, or can be, given from which an opinion can be formed as to whether or not the decay is normal or abnormal in character. The two exceptions are the cases of the Pedregulho reservoir in Rio de Janeiro and of the new shafts of the Morro Velho mine in Minas Geraes for both of which the figures are definite and the conditions are such that the decay observed may be considered as about normal for the kinds of rocks concerned.

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[1] The subject of faulting has received very little attention in the study of Brazilian geology, but it is becoming apparent that many of the topographical features are due to faults and their determinative effects upon erosion rather than to erosion pure and simple as generally assumed. The evidences of faulting are most apparent in the regions of horizontal sedimentaries and bedded eruptives of the southern part of the country, but there are reasons for believing that they will also be found, perhaps on an equal scale, when detailed studies are made of the more ancient regions of eastern and central Brazil and of the more modern ones of the northern part of the country. For the latter region the possibility of faulting was suggested, rather too obscurely, as it appears, in a brief résumé of what was known of the Cretaceous in Brazil prepared by the present writer to accompany the monograph of Dr. C. A. White on the fossils of that age (Archivos do Museu Nacional do Rio de Janeiro, Vol. VII). The paragraph in which attention was called to the comparatively low level of the fossiliferous coastal basins as compared with the beds of the interior referred to the same age but with, so far as known, a different fauna, suggestive of a possible rise of the land occurring between the two faunas, has been strangely misapprehended by Dr. Branner who characterizes it as a hypsometric classification of formations. (The Cretaceous and Tertiary Geology of the Sergipe-Alagôas basin of Brazil, Trans. Am. Phil. Soc., Vol. XVI, 1889, p. 410.) As he unites the two faunas on no better ground than the attempted refutal of the supposed low level of the coastal basins, the epithet may perhaps with greater justice be applied to his own reasoning. The refutal in question is contained in the statement that the Cretaceous beds extend to within 150 meters of the top of the Serra de Itabaiana which, according to Mouchez,

The Pedregulho hill is an isolated elevation surrounded by tidal swamps and old beach deposits, of the type so well described by the Brazilians as a half orange. It thus presents the most favorable disposition for the preservation of the decomposed material except for the inevitable waste from rain washing and wind action, and (at least since the present topographical conditions were established) it has received no material from adjacent higher lands and only its own proper amount of atmospheric waters. The cutting away of the top of the hill for the reservoir foundation exposed the upturned edges of a highly schistose gneiss in which the different layers, rarely more than a few centimeters thick, vary greatly in the relative proportions of quartz, feldspar and mica (biotite) and consequently in permeability and susceptibility to decay. On the whole, however, it may be said that the rock represents the most susceptible type of the neighborhood and is in the most favorable conditions for rapid decay. At the depth of sixty-five feet from the original summit of the hill the rock was considered sufficiently firm to build upon though it was nowhere perfectly sound and many of the layers were completely earthy, partial decomposition evidently extended much deeper, and it may even be presumed that in some of the layers it may have extended nearly or quite to drainage level, that is to say to near the base of the hill 225 feet below the original summit.

In the case of the Morro Velho mine the rock concerned is a hard bluish clay slate, but without well defined slaty cleavage, standing nearly vertically. It is very uniform in character and

rises to an elevation of 700 to 800 meters above tide. Mouchez's figures are presumably a sailor's estimate at long range and are not in accord with two aneroid determinations which gave 520 and 608 meters. The section and detailed description of the mountain given in the same paper represent, in perfect accord with my own observations in the region, the Cretaceous beds as terminating at some distance from the base of the mountain, at an elevation of about one-third of its height and only slightly greater than that of the Tertiary which is stated to be about 200 feet. So far as the present evidence goes, therefore, the original estimate of about 100 meters as the maximum elevation of the coastal beds may still stand. As at no great distance the base of a very extensive and apparently very different horizontal series of secondary beds is at an elevation of about 300 meters, faulting is strongly suggested.

texture throughout a considerable thickness and, so far as can be judged from a simple inspection, should be one of the least susceptible to decay of the series of metamorphic schists to which it belongs. The notes given by Branner refer to two sets of shafts which should be carefully discriminated. The first were sunk at the bottom of a gorge, possibly a fault line, and thus were almost wholly below drainage level. The term "jointy" applied in the mine report to the first dozen fathoms would hardly be used by miners for a decomposed condition of the rock so that the depth of timbering (126 feet) is probably a measure of the depth to which the rock was shattered, perhaps through faulting, rather than decay. The new shafts, to which the information given by the present superintendent refers, are so situated that the depth at which "blasting rock" was found affords a good measure of the normal decay of this class of rocks above drainage level. They are on the side of a campo-covered ridge with a slope of 20° to 30° to the nearest stream some 300 feet below the mouth of the shafts. Decomposition here, though profound (155 feet), is still far above drainage level and probably under the same circumstances the more permeable rocks of the same series (especially those in which rapid alternations of layers of different composition and texture occur) would be found decomposed to a much greater depth. Thus in the adjoining Faria mine the depth cited (164 feet) probably refers to the depth of working and not to that of decay which under the circumstances of the mine and of its rock may be very much greater. On the other hand the soft bed intercalated in hard rock reported at Morro Velho at a depth of 755 feet could hardly have been a case of normal decay. So also the soft (friable) rock reported in the Cocaes (300 feet) and Gongo Socco (375 feet) mines probably do not represent decomposition as it is very doubtful if the rock of these mines (itabirite) was ever in a compact condition.

In traveling through the mining districts of Minas Geraes, which are mainly in campo, one gets the impression that rock decomposition is even more profound than in the forested coastal region. In part the predominant rocks are of a totally different character representing in general terms the so-called crystalline schists with the exclusion of the true gneisses, and taken as a whole, it may perhaps be assumed that they are more susceptible to decay than the rocks of the coastal region in which gneiss and granite predominate. The comparison to be a fair one should be made between campo and forest region constituted by rocks of, as nearly as may be, the same character. The only elements for such a comparison are the superficial observations from the car window in traveling over the Central Railroad. In the long stretch of line in the forested region from Rio de Janeiro over the Serra do Mar and along the Parahyba and Parahybuna valleys to the crest of the Mantiqueira range one seldom fails to see sound rock, gneiss or granite or both, in the bottom (and often in the entire side) of cuttings that exceed a moderate depth. After passing the crest of the Mantiqueira and entering the campo region of Barbarcena sound rock is the exception rather than the rule in the cuttings though these continue as numerous and deep as in the other section and are also, for the most part, in gneiss and granite. The appearance, possibly deceptive, is that decomposition is even more profound in the campo than in the forest region. One plausible explanation for this difference is topographical, since in the forest region the road mainly follows the valleys and is consequently near drainage level whereas in the campo region it is more independent of the streams and is in general considerably above that level The rocks also, although of the gneiss and granite type, are apparently more acid in composition with a greater abundance of free quartz and of potash mica while magnesia, mica and amphibole are the predominant bisilicates in the rocks of the forest region. There are many indications that this difference in composition is accompanied by a greater susceptibility to decay although exact observations on this point have not been recorded. The differences noted in topographical structure and in rock composition may account for the apparently greater decay in the campo region and in that case the decay in the two regions contrasted may be taken as approximately equal. So far as the present evidence goes, however, it is to the effect that in the districts of highly inclined crystalline and metamorphic schists of the states of Minas Geraes and Rio de Janeiro profound rock decomposition is not a concomitant of the present distribution of forests.

An interesting feature in the decay of some types of granite is that a considerable portion of the feldspar resists decomposition almost as well as the quartz and the rock disintegrates into a coarse gravel with comparatively little earthy, or completely decomposed, elements. This was first noticed on any considerable scale in a relatively arid region along the São Francisco River and was thought to be a case of arrested decay due to deficient rainfall. It has since been found, however, to be independent of climate as in the same region some rocks may be found decayed in this way while others in the immediate neighborhood are completely decomposed. Curiously enough the soils in which only a portion of the silicate elements of the original rock have become earthy are considered very good and in São Paulo these "rock-salt" (*salmarão*) soils are favorite ones with coffee planters.

With the rocks thus far considered, that is to say, the crystalline and metamorphic schists and their associated granites, decomposition, although very variable, is undoubtedly extensive and, very probably, is in many points much more profound than in any of those at which accurate measurements, or estimates, have been made. In general, however, it is to be measured by scores and not by hundreds of feet and, so far as the present evidence goes, the differences to be noted from one point to another are rather to be attributed to original differences in susceptibility, in permeability (due to original or superinduced textural and structural features), in the position of the rock masses in their exposition to the agencies of decay or with reference to the drainage level, rather than to climatic or biologic causes. With reference to this last point it would be interesting to compare the regions above considered with such a one as that mentioned by Allen[1] in the semi-arid region of Central Bahia, where gneiss and granite appear in a vast and almost level plain with only a slight covering of decomposed material. For this, however, data is lacking and it is impossible to say how much of the characteristics of this region is to be attributed to climate alone.

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[1] HARTT, Geol. and Phys. Geog. of Brazil, p. 314.

Turning our attention now to other groups of rocks, some of these are found to have resisted remarkably well the "torrents of hot water falling for ages in succession upon hot stones" in the phrase of Professor Agassiz. (The temperature of 140° to 150° F. recorded by Caldcleugh for rain water running over exposed rock surfaces would seem to require confirmation.) In crystalline rocks in which the inalterable quartz is replaced by silicates susceptible of alteration, such as nepheline and sodalite, much more rapid and profound decomposition might be expected than in the granites and gneisses. On the contrary, however, these, though decayed in places, are generally found in a sound condition at or near the surface. With many of these rocks a peculiar crust of kaolin and limonite forms on the surface of the decayed portion which serves as a very efficient protection for the inner portion of the masses. The more feldspathic types (augite-syenite) seem, contrary to what might be expected, to be more susceptible to decay than those rich in the silicates above named. The character of the bisilicate element also seems to be of considerable importance as in a recent excursion to the peak of Itatiaia no difficulty was experienced in obtaining satisfactory specimens from the exposed blocks, or bosses, of nepheline-syenite, augite-syenite, phonolite and even tufas, whereas a very extensive exposure of mica-syenite was searched in vain for a perfectly sound sample of the rock. In this, as in some other cases, it looks as if some of the elements set free by the decay of the rock itself might be more potent for continued decomposition than those derived from the atmosphere. The general soundness, though many exceptions occur, of the porphyritic (phonolitic) types of these rocks is especially noticeable as it is understood that in many temperate regions this type, though presumed to be geologically newer than in Brazil, is considered to be particularly susceptible to alteration.

An opportunity for observing the phenomena of decomposition under substantially the same climatic and biologic conditions but with reference to a totally different series of rocks is afforded by the recent notable extension of coffee culture in the interior of the state of São Paulo with the accompanying extension of the railway system. No critical study of this region has as yet been made and, as in nearly all that precedes, the observations (whether those of the writer or of others) must be taken as railroad geology and, as such, subject to future revision.

The region in question lies immediately to the west of that above considered and in so nearly the same conditions as regards latitude, elevation, rainfall, and forest distribution that the differences may be considered as unimportant for the present discussion. The features of geological and topographical structure and of the character of the rocks are however widely different. The dominant geological and topographical features are given by soft shales and sandstones of late palæozoic (Permian ?) and early secondary (Triassic ?) age which are practically horizontal though much disturbed by faults and dykes and sills of basic eruptives. The latter belong exclusively to the group of augite-porphyrites as defined by Rosenbusch and represent all the varied phases of that group. According to all the indications at present known the region has stood as dry land ever since early secondary times. Much of it is in campo but considerable forest tracts occur. No direct relation can be traced between the distribution of forest and campo and the character of the underlying rocks, though in general it may be said that campo predominates over forest in the areas in which the sedimentaries give character to the surface soil, the contrary being the case where the eruptives come to the surface.

In this region the evidences of profound decomposition are far less prominent than in the mountainous districts above referred to. The railroad cuttings are not deep, seldom exceeding a half dozen meters, but they rarely fail to show some rock in a comparatively sound condition which frequently extends to within a meter or less of the surface. The sedimentary rocks are almost invariably quite soft even where they show no signs of decay, and go to pieces by a kind of slacking process when broken up and exposed to the air, though they may have required blasting in the original opening of the cuttings. The eruptive rocks vary greatly in their resistance to decay. The porphyritic types, especially when they are amygdaloidal, are often in a state of incipient, or complete, decomposition to a depth quite as great, or perhaps even greater, than that noted in the granite and gneiss regions, while the types approaching diabase in character are often sound, or only broken up into bowlders of decomposition, quite to the surface. As the decay of these basic rocks affords the favorite coffee soil, the famous *terra roxa*, the forested tracks where they occur have been very generally cleared and planted, and the coffee orchards (where the underlying rock is diabasic) seldom fail to show loose stones and frequently continuous outcrops of rock at the surface. Many of these orchards are on almost level tracts, so that the comparative thinness of the capping of decomposed rock cannot be attributed to excessive washing. In short, considering the length of time that this region has stood as dry land and the favorable topographical disposition for the preservation of the products of decay, the average amount of rock decomposition may be said to be surprisingly small rather than surprisingly great, and where it is profound, the cause must be sought in the susceptibility of the rocks themselves and not in climatic or biologic conditions.[1]

ORVILLE A. DERBY.

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[1] In treating of the organic agencies affecting the soil, Dr. Branner notes that the action of earth worms is much less important in Brazil than in temperate regions. The same remark has been made by Mr. H. H. Smith, a very acute and accurate geological and biological observer. My own experience is so far in accord with these observations that only once has decided evidence of the action of earth worms been noticed. This case however was so striking that the absence of other observations may perhaps be attributed rather to lack of attention to the subject, or of favorable conditions for observing the action of these humble manipulators of the soil, and not to their absence. An old pasture that had been wet by a shower after a burning that had completely bared the surface, was so thickly covered with the vermicular heaps thrown up by earth worms that over a space of several acres it was almost impossible to put down the hand without touching one or more of them.